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14. ABSTRACT
This research aims to develop new optimization models and algorithms for project scheduling under both resource constraints and uncertainties, a problem known as the stochastic resource-constrained project scheduling problem (SRCPSP) in the operations research (OR) and scheduling literature. In a typical SRCPSP, a decision-maker attempts to obtain a feasible schedule of project tasks such that: (i) their temporal/precedence relationships are satisfied; (ii) the available resource capacity is not exceeded in each time period; and (iii) the expected project makespan is minimized. Using the developed modeling and solution methodologies, it is our goal to enhance the

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Hai Tao Li
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Report Title

Final Report: Resource-Constained Project Scheduling Under Uncertainty: Models, Algorithms and Applications

ABSTRACT

This research aims to develop new optimization models and algorithms for project scheduling under both resource constraints and uncertainties, a problem known as the stochastic resource-constrained project scheduling problem (SRCPSP) in the operations research (OR) and scheduling literature. In a typical SRCPSP, a decision-maker attempts to obtain a feasible schedule of project tasks such that: (i) their temporal/precedence relationships are satisfied; (ii) the available resource capacity is not exceeded in each time period; and (iii) the expected project makespan is minimized. Using the developed modeling and solution methodologies, it is our goal to enhance the quality of decision-support for scheduling complex large-scale projects in military, manufacturing, construction and professional service sectors.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 4.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
01/18/2011	1.00	H. Li. CP-Based Approximate Dynamic Programming and Its Application for Solving the Deterministic Resource-Constrained Project Scheduling Problem, (01 2011)
01/18/2011	2.00	H. Li, K. Womer. Stochastic Resource-Constrained Project Scheduling and Its Military Applications, (01 2011)
02/03/2011	3.00	H. Li. Approximate Dynamic Programming Algorithms for Resource-Constrained Project Scheduling with Stochastic Task Durations, (01 2011)
02/15/2011	4.00	H. Li. 2011 Project Summary Resource-Constrained Project Scheduling under Uncertainty: Models, Algorithms and Applications , (09 2010)
08/18/2011	5.00	Haitao Li. An Approximate Dynamic Programming Algorithm for the Resource-Constrained Project Scheduling Problem with Stochastic Task Durations, (submitted) Journal of Heuristics (08 2011)
09/06/2012	6.00	Keith Womer, Haitao Li. Optimizing the Supply Chain Configuration for Make-to-Order Manufacturing, European Journal of Operational Research (01 2011)
11/10/2014	8.00	Norman Keith Womer, , Jeffrey Camm, Colin Osterman, Haitao Li, Rajesh Radhakrishnan. Make-to-Order (MTO) Production Planning using Bayesian Updating, International Journal of Production Economics (04 2014)
11/10/2014	7.00	Norman Keith Womer, Haitao Li. Solving Stochastic Resource-Constrained Project Scheduling Problems by Closed-Loop Approximate Dynamic Programming, European Journal of Operational Research (05 2014)
TOTAL:	**8**	

Number of Manuscripts:

Books

Received	Book
TOTAL:	

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Yejing Shan	1.00	
Stan Solomon	1.00	
FTE Equivalent:	**2.00**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Haitao Li	0.20	
FTE Equivalent:	**0.20**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attached Final Report and the Research Manuscripts

Technology Transfer

- With The U.S. Army TRADOC Analysis Center (TRAC) in Monterey, CA: Collaboratively developing new RCPSP based optimization models for the Unmanned Aerial Vehicle (UAV) Assignment and Scheduling Problem (See Appendix-I).
- With HP Labs (HPL) in Palo Alto, CA: Collaboratively developed a new model and solution approach to simultaneously optimize project portfolio selection and planning.

Resource-Constrained Project Scheduling under Uncertainty: Models, Algorithms and Applications

Haitao Li
Department of Logistics and Operations Management
College of Business Administration
University of Missouri, St. Louis, MO 63121

I. Research Objective

This research aims to develop new optimization models and algorithms for project scheduling under both resource constraints and uncertainties, a problem known as the stochastic resource-constrained project scheduling problem (SRCPSP [1]) in the operations research (OR) and scheduling literature. In a typical SRCPSP, a decision-maker attempts to obtain a feasible schedule of project tasks such that: (i) their temporal/precedence relationships are satisfied; (ii) the available resource capacity is not exceeded in each time period; and (iii) the expected project makespan is minimized. Using the developed modeling and solution methodologies, it is our goal to enhance the quality of decision-support for scheduling complex large-scale projects in military, manufacturing, construction and professional service sectors.

II. Technical Approach

Solving an SRCPSP is challenging because: (i) its deterministic counterpart, namely, the RCPSP, is well-known to be *NP-complete* with a large combinatorial solution space; (ii) one also needs to consider a large number of scenarios about the random problem parameters, e.g., stochastic task durations. In this research, we model the SRCPSP as a sequential decision problem under uncertainty, known as Markov decision process (MDP [2]). To overcome the well-known "curse-of-dimensionalities" of the classical dynamic programming (DP) method based on the exact Bellman recursion, we have developed an approximate dynamic programming (ADP [3]) solution framework to obtain computationally tractable near-optimal solutions.

A schematic sketch of the algorithmic structure is provided in Figure 1. It is built upon three main techniques, i.e. forward iteration, value function approximation and deterministic solver. Instead of iterating backward as in the classical Bellman recursion, ADP steps forward in time following a particular sample path of random parameters generated by Monte Carlo simulation. This avoids the need of exhaustively visiting all possible MDP states. The essence of ADP is to replace the exact cost-to-go function with some form of approximation, e.g., through valuation function approximation, or the rollout policy [4] that works well for combinatorial optimization. In addition, an effective and efficient deterministic solver is needed to handle the deterministic sub-problem associated with a particular sample path in each ADP iteration. Due to combinatorial nature of SRCPSP, traditional math programming methods, such as linear programming and integer-programming, are often not able to perform well. An innovative component in our ADP algorithm is to employ constraint programming (CP [5]) based methods, originated in the artificial intelligence (AI) area, to model and solve the sub-problem in each ADP iteration. A flow chart of the basic hybrid CP-ADP algorithm is provided in Figure 2, where constraint propagation and CP search procedures are employed as the base policy for solving each sub-problem.

III. Research Significance

Our new modeling and solution methodologies for SRCPSP developed in this research project have significantly advanced the state-of-the-art research and practice in project scheduling. Figure 3 depicts the evolution of research on scheduling projects/programs since the 1950's. Although widely used today, neither the well-known critical path method (CPM) nor the program evaluation and review technique (PERT and the later GERT), copes with the issue of limited resource availability. Majority of the research in the past three decades have focused on the deterministic RCPSP; while the more realistic and challenging SRCPSP has attracted much research efforts in recent years.

Most of the existing solution approaches to SRCPSP are *open-loop* in nature, because they attempt to find a feasible sequence/schedule of all tasks at the time of project start, without utilizing information arrived during project execution. Such predetermined schedule is *static* and not updated during real-time execution. In contrast, our ADP framework is a *closed-loop* approach, where scheduling decisions are made in a *sequential* and *dynamic* fashion, which is more flexible than an open-loop solution. The main technical innovation of our solution approach is the integration of optimization, simulation and CP in a unified ADP framework. Table 1 shows that our ADP algorithm outperforms an open-loop GRASP approach by Ballestin and Leus [6] on the 120-task PSPLIB benchmark instances. Notably, for task durations with non-symmetric probability distribution (exponential and beta distributions), our closed-loop ADP algorithm outperforms GRASP by significant margins in solution quality.

Since RCPSP is general enough to include various types of scheduling problems such as job shop, flow shop, and open shop in machine scheduling, as special cases, our ADP framework can be adapted to deal with the stochastic version of these problems. From the practical perspective, our sequential and dynamic closed-loop solution framework enables the data-driven decision-making paradigm, made possible by the fast growth of IT infrastructure and availability of data.

IV. Scientific Barriers

The solution methodologies developed in this project assume that probability distribution of random parameters is known *a priori*, which is a typical assumption made in *stochastic optimization*. In real world applications, however, probability distribution of task duration can either be hard to estimate due to the lack of historical data for a new project; or may evolve over time. This leads to an SRCPSP with an *incomplete information process*. The PI's ongoing research focuses on developing integrated Bayesian updating and ADP methods for optimization with incomplete information about uncertain parameters.

V. Accomplishments

Accomplishment-1: Designed and implemented integrated CP-ADP algorithm for obtaining near-optimal solutions to SRCPSP, which outperforms the state-of-the-art algorithm available.

- Li, H. and K. Womer (2014) Solving Stochastic Resource-Constrained Project Scheduling Problems by Closed-Loop Approximate Dynamic Programming, under second-round review in *European Journal of Operational Research*.

Accomplishment-2: Relevant applications in military and manufacturing sectors.

- Li, H. and K. Womer (2011) Stochastic Resource-Constrained Project Scheduling and Its Military Applications, *MORS Phalanx*, March.
- Li, H. and K. Womer (2012) Optimizing the Supply Chain Configuration for Make-to-Order Manufacturing, *European Journal of Operational Research*, 221(1): 118-128.

Accomplishment-3: Developed integrated Bayesian updating and ADP algorithm for sequentially and adaptively optimizing production planning in Made-to-Order programs with *incomplete information*.

- K. Womer, J. Camm, C. Osterman, R. Radhakrishnan, and H. Li (2013) Made-to-Order Production Scheduling using Bayesian Updating, Working Paper, under second-round review in *International Journal of Production Economics*.

VI. Collaborations and Technology Transfer

During the grant effort, I have been actively collaborating with various industrial partners on relevant real world applications.

- With The U.S. Army TRADOC Analysis Center (TRAC) in Monterey, CA: Collaboratively developing new RCPSP based optimization models for the Unmanned Aerial Vehicle (UAV) Assignment and Scheduling Problem (See Appendix-I).
- With HP Labs (HPL) in Palo Alto, CA: Collaboratively developed a new model and solution approach to simultaneously optimize project portfolio selection and planning.
- With Mallinckrodt Inc., a pharmaceutical company in St. Louis, MO: Developed a research proposal "Accelerating Bioscience Discovery: Learning, Inference and Modeling", submitted to the NSF EPSCoR Program.
- With several construction companies in Kansas City, MO: Collaboratively developing new RCPSP based optimization models for construction project scheduling and resource allocation.

VII. Leveraged Funding

- PI, "Optimizing the Project Portfolio Design and Staffing Decisions for Professional Service Enterprises", sponsored by HP Labs Innovative Research Program, $32,200, August 2010 to July 2011.
- PI, "Models and Algorithms for Stochastic Resource Planning", sponsored by HP Labs Innovative Research Program, $72,587, August 2011 to July 2012.
- PI, "Project and Resource Optimization", sponsored by HP Labs Innovative Research Program, $67,000, August 2012 to July 2013.
- CO-PI, "Decision Support Tool Model for Scheduling and Resource Allocation in Construction Projects through Application of Operations Research Methods", sponsored by the Interdisciplinary/Intercampus Research Grants of UM System, $37,600, June 2013 to May 2014.

VIII. Conclusions

In this ARO-sponsored research project, the PI and his team of collaborators have developed computationally tractable ADP algorithms for obtaining high-quality near optimal solutions to the MDP model of SRCPSP. It offered a first successful development and implementation of a sequential and dynamic closed-loop solution paradigm for solving this class of high-dimensional MDPs. Our ADP algorithm framework integrates solution techniques in optimization, simulation and artificial intelligence to overcome the computational challenge due to curse-of-dimensionalities. Computational experiments on benchmark instances indicate that our new closed-loop ADP algorithms outperform the state-of-the-art open-loop algorithms for this category of stochastic optimization problems. In addition, our research team has also explored applications of RCPSP on scheduling, production planning, resource allocation and portfolio selection in various domains including military, manufacturing, construction and professional service. These applications have opened the door of leveraging the modeling and computational advancement of ADP for SRCPSP in real life applications.

IX. Technology Transfer

The PI has been working closely with the Technology Commercialization and Economic Development Department at the University of Missouri – St. Louis (UMSL) on the technology transfer side of the project. Since 2012 two provisional patents and a U.S. patent have been filed:

- Li, H. (2013). *System and Method of Stochastic Resource-Constrained Project Scheduling*, U.S. Patent Application 61/795,574, filed in October 2013, Patent Pending. (Appendix-II)
- Li, H. (2012). *Hybrid Architecture in Approximate Dynamic Programming for Project Scheduling*, Provisional Patent, Attorney Docket Number: 13UMS002prov.
- Li, H. (2012). *Stochastic Resource-Constrained Project Scheduling*, Provisional Patent, Attorney Docket Number: 11UMS001prov.

Another avenue of technology transfer effort the PI has been pursuing is the collaboration with the U.S. Army TRAC – Monterey on their UAV assignment and scheduling application. Our conversation started in the Army's Applied Statistics Conference in Monterey, CA in October 2012, when we identified that the complex and dynamic nature of the military UAV scheduling problem calls for a sequential decision paradigm modeled by MDP; and the successful outcome of this project warrants our collaboration to jointly develop new ADP model and solution approach to enhance the performance and capability of their current Assignment Scheduling Capability for Unmanned Aerial Vehicle (ASC-U) tool. Once proved to be effective, the new model and solution approach have the potential to replace the existing ASC-U tool. Our collaborative agreement is attached in Appendix-I.

X. Future Plans

The outcome and deliverable of this ARO sponsored project have paved the way for future research on project scheduling under uncertainty. The goal is to continue building and refining dynamic and adaptive data-driven models and algorithms to enhance the quality of decision-making in project scheduling and resource allocation in various application domains. The PI has made a clear and detailed plan about how to proceed.

- Basic research on project scheduling under uncertainty and *incomplete information process*, where the decision maker does not know *a priori* the probability distribution of uncertain problem data such as task duration, resource availability, etc. The PI and his research team have already started their efforts in investigating such more realistic and challenging problem setting in the context of construction project scheduling (Li and Halmen 2013 in Accomplishment-2) and made-to-order (MTO) production planning (Womer et al. 2013 in Accomplishment-3). We have developed integrated Bayesian updating and ADP algorithms to jointly obtain/improve the posterior probability distributions and to optimize decision-making with more information/data available.
- Basic research on our ADP framework for stochastic machine scheduling problems: flow shop, job shop and open shop, etc. Since many classical machine scheduling problems are special cases of RCPSP, the modeling and solution framework developed in this project for SRCPSP can be applied.
- Applied research on real world applications including the UAV assignment and scheduling and mission planning applications in military, project portfolio and resource planning in professional service, and project scheduling in the construction and pharmaceutical industries.

The support from the ARO has been crucial for the PI to initiate and build up this line of research over the past four years, with his collaborators in both academia and industry. The PI appreciates ARO's continuing support in this and other related line of research in the future.

References

[1] Demeulemeester, E.L. and W.S. Herroelen, *Project Scheduling: A Research Handbook*. International Series in Operations Research and Management Science. 2002, Norwell, MA: Kluwer Academic Publishers.

[2] Puterman, M.L., *Markov Decision Processes: Discrete Stochastic Dynamic Programming*. Wiley Series in Probability and Statistics. 2005: John Wiley & Sons Inc.

[3] Si, J., A.G. Barto, W.B. Powell, and D. Wunsch, *Handbook of Learning and Approximate Dynamic Programming*. IEEE Press Series on Computational Intelligence. 2004: Wiley.

[4] Bertsekas, D., J.N. Tsitsiklis, and C. Wu, Rollout algorithms for combinatorial optimization. *Journal of Heuristics*, 1997. **3**(3): p. 245-262.

[5] Marriott, K. and P.J. Stuckey, *Programming with Constraints*. 1998, Cambridge, Massachusetts: The MIT Press.

[6] Ballestin, F. and R. Leus, Resource-constrained project scheduling for timely project completion with stochastic activity durations. *Production and Operations Management*, 2009. **18**(4): p. 459-474.

Appendix – 1

MEMORANDUM OF AGREEMENT

BETWEEN

THE U.S. ARMY TRADOC ANALYSIS CENTER (TRAC)

AND

DEPARTMENT OF LOGISTICS AND OPERATIONS MANAGEMENT
COLLEGE OF BUSINESS ADMINISTRATION
THE UNIVERSITY OF MISSOURI, SAINT LOUIS

SUBJECT: Agreement to Obtain Access to and Use of Assignment Scheduling Capability for Unmanned Aerial Vehicles (ASC-U).

1. This Memorandum of Agreement (MOA) establishes procedures for Department of Logistics and Operations Management, College of Business Administration, The University of Missouri, Saint Louis, hereafter the Activity, to obtain access to and use of the Assignment Scheduling Capability for Unmanned Aerial Vehicles software, developed by the TRADOC Analysis Center and the Naval Postgraduate School (NPS) and hereafter referred to as ASC-U. ASC-U refers to the most recent version available for download through the NPS Modeling, Virtual Environments and Simulation (MOVES) Institute, and access to the java code base.

2. The TRADOC Analysis Center, hereafter the ASC-U Sponsor, agrees to provide ASC-U to the Activity in performance of specific research tasks or contracts which will be specified in the Memorandum Annex(es). Each Annex forwarding ASC-U to the Activity will describe ASC-U, specify the conditions under which the ASC-U is being provided, any services related to ASC-U which are to be provided by ASC-U Sponsor, and specify that ASC-U is being provided pursuant to this MOA. Conditions may include payment of a fee or fees for some or all of ASC-U. The Activity agrees to: safeguard ASC-U, including data, scenarios, documentation, and any other ancillary materials; to distribute ASC-U to only those identified in writing and agreed to by the ASC-U Sponsor; to execute prior to delivery of ASC-U inclusion of the provisions contained in the Memorandum Annex(es) in contracts, task orders, or other appropriate legally binding documents with contractor(s) who will be provided access to ASC-U; to enforce the Memorandum Annex(es); and upon request of the ASC-U Sponsor, to direct contractor(s) to return ASC-U to the ASC-U Sponsor. Should the Activity retain or use ASC-U, it agrees to comply with the provisions contained in the Memorandum Annex(es).

3. Any expenses incurred in performance of this MOA and Memorandum Annex(es) are the responsibility of the Activity. The ASC-U Sponsor shall not be responsible for any of these expenses.

Subject: Agreement to Obtain Access to and Use of ASC-U

4. This MOA will become effective upon signature of all parties. The parties agree that the MOA and the Memorandum Annex(es) shall govern ASC-U and its contractor(s). The MOA will remain in effect until five years after its effective date unless earlier revoked in writing by either the Activity or the Sponsors. The Activity agrees to enforce the provisions contained in the Memorandum Annex(es) even after termination of the MOA.

For the Department of Logistics and Operations Management, College of Business Administration, UMSL

HAITAO LI
Assistant Professor of Logistics and Ops Mgt.
University of Missouri, Saint Louis

03/20/2013
Date

ROBERT NAUSS
Professor and Chair
Department of Logistics and Ops Mgt.
University of Missouri, Saint Louis

03/20/2013
Date

KEITH WOMER
Professor and Dean
College of Business Administration
University of Missouri, Saint Louis

3/20/2013
Date

For the TRADOC Analysis Center:

PAMELA I. BLECHINGER
SES, U.S. Army
Director
TRADOC Analysis Center

3/26/2013
Date

Appendix – 2

THOMPSON COBURN LLP

Kevin M. Kercher
P 314.552.6345
F 314.552.7345
kkercher@thompsoncoburn.com

October 18, 2013

VIA E-MAIL

Craig Weilbaecher, PhD
Licensing and Business Development Associate
Technology Commercialization and Economic Development
Office of Research Administration
University of Missouri-St. Louis
M208 Center for Nanoscience, One University Blvd.
St. Louis, MO 63121

Re: U.S. Patent Application for *System and Method of Stochastic Research-Constrained Project Scheduling;* Serial No. 14/057,776; Filed October 18, 2013
Your Ref. 11UMS001; Our Ref: 65000-126731

Dear Craig:

Enclosed for your records is a copy of the subject application which has been electronically filed with the U.S. Patent and Trademark Office. The application has received a filing date of October 18, 2013, and has been assigned Serial No. 14/057,776. In time, we will be receiving notification of a filing receipt as well as additional actions from the Patent Office. We will keep you advised as we receive further information.

Now that the application has been filed, and is therefore pending in the U.S. Patent and Trademark Office, you may now mark any products utilizing the invention, and any brochures, drawings, advertising, and the like describing the invention, with the words "PATENT PENDING", and you may continue to do so until a patent issues on your application or the application becomes abandoned. If you have any questions about this please give me a call.

Publication:

We have filed the application under normal procedures, which will result in its publication. The projected publication date for the application is April 18, 2013. The Patent Office will publish the application on this date, or promptly thereafter, unless: (1) the application becomes abandoned prior to April 18, 2013 and within sufficient time for the Patent Office to remove the application from its publication process, which the Patent Office estimates as at least 4 weeks prior to the projected publication date; or (2) the application is national security classified, subject to a statutory secrecy order, or under national security review. Publication of the application also will not occur if the application issues as a patent prior to publication and within sufficient time for the Patent Office to remove the application from its publication process, but in such case, of course, the patent itself is published. You should also bear in mind that the Patent Office does not guarantee that it will remove an application from the publication process if the

application becomes abandoned at any time after the publication process for the application has been initiated.

You also have the option of submitting a request for early publication if you desire publication prior to April 18, 2013. It may be desirable to request early publication if you are aware, or become aware, of any competitors who may be making, using, offering for sale, selling, or importing into the United States the invention embodied in the claims. Early publication will provide an earlier date upon which a possible infringer may become liable for certain infringement damages. However, it must be noted that the Patent Office will not honor requests for a specific publication date. The Patent Office charges a $300.00 fee for early publication. If you are interested in pursuing early publication of the application, please let me know so that we can submit an early publication request to the Patent Office.

Continuing Duty to Disclose:

We wish to remind you of the duty to disclose to the U.S. Patent and Trademark Office all information of which we have knowledge that may be material to the examination of the patent application. Information is considered "material" when (1) it establishes, by itself, or in combination with other information, a lack of novelty or unobviousness of the invention, (2) it argues against enablement of the invention, or (3) it refutes or is inconsistent with a position the applicant takes (or anticipates taking) in opposing an argument of unpatentability relied on by the Patent Office or when asserting an argument of patentability. The duty applies to the inventors, their attorneys, any person substantively involved in the preparation and prosecution of the application, and other representatives and their assignees.

To comply with this duty, in addition to any information that you may have furnished us previously, please conduct a thorough examination of the files under your control which may contain additional material information. Please be particularly alert for: (1) patents and other publications which could have a bearing on the novelty, obviousness or enablement of the invention; (2) all uses of the invention, including demonstrations to and uses by third parties, and all test data, whether favorable or unfavorable; and (3) all marketing activities involving the invention including sales solicitations. Please also note that information generated or published after the filing date of your application (i.e. "non-prior art" references) may be material to patentability, particularly when "enablement" of the pending claims has been questioned or is anticipated to be questioned. Once this information is gathered, we will file the "material" information that you provide in an Information Disclosure Statement with the Patent Office.

Please be aware however that information that is not "material" to the patent application should not be included in the Information Disclosure Statement (IDS). It is understandable that the inventor(s), in an effort to be thorough, may tend to disclose an abundance of references without carefully considering their materiality. However, because of the heavy volume of patent applications faced by the Patent Office, an examiner may refuse to consider an Information Disclosure Statement comprised of a large number of non-material references. Also, an opposing party may allege that we are attempting to "bury" key material references by disclosing

an over-abundance of non-material references in the IDS. Thus, non-material information must be culled before submission of the Information Disclosure Statement to the Patent Office. We invite you to determine the materiality of the information that you have gathered prior to submitting that information to us. We can of course assist you by providing some further interpretive help for determining materiality and answering any specific questions that you may have. If you would prefer, we can also review your references to determine their materiality on your behalf. Please note, however, that our efforts to determine materiality of the information you provide may require significant billable time and thus incur additional expenses, especially in the event that a large number of references are provided for our review.

The duty to disclose is of a continuing nature. Therefore, if at any time during the pendency of this application you become aware of additional material information, please advise us so that we can disclose it to the Patent Office.

In order to comply with this duty, we must file the Information Disclosure Statement and accompanying material references with the Patent Office, preferably within three months from the date of filing the application or before the mailing date of the first Office Action so as to minimize fees. After you have thoroughly reviewed your files, please contact me with any additional information so we can discuss the preparation of this document.

If you have questions relating to publication, or any other matter, please do not hesitate to contact me.

Very truly yours,

Thompson Coburn LLP

By
Kevin M. Kercher

KMK/jbg

Enclosure

cc: Tamara Wilgers